Recent Climate Variability in Antarctica from Satellite-Derived Temperature Data

David P. Schneider and Eric J. Steig*

Department of Earth and Space Sciences, University of Washington, Seattle, Washington

Josefino C. Comiso

Laboratory for Hydrospheric Processes, NASA Goddard Space Flight Center, Greenbelt, Maryland

(Manuscript received 10 March 2003, in final form 2 September 2003)

ABSTRACT

Recent Antarctic climate variability on month-to-month to interannual time scales is assessed through joint analysis of surface temperatures from satellite thermal infrared observations (T_{IR}) and passive microwave brightness temperatures (T_B). Although T_{IR} data are limited to clear-sky conditions and T_B data are a product of the temperature and emissivity of the upper ~1 m of snow, the two datasets share significant covariance. This covariance is largely explained by three empirical modes, which illustrate the spatial and temporal variability of Antarctic surface temperatures. The T_B variations are damped compared to T_{IR} variations, as determined by the period of the temperature forcing and the microwave emission depth; however, microwave emissivity does not vary significantly in time. Comparison of the temperature modes with Southern Hemisphere (SH) 500-hPa geopotential height anomalies demonstrates that Antarctic temperature anomalies are predominantly controlled by the principal patterns of SH atmospheric circulation. The leading surface temperature mode strongly correlates with the Southern Annular Mode (SAM) in geopotential height. The second temperature mode reflects the combined influences of the zonal wavenumber-3 and Pacific–South American (PSA) patterns in 500-hPa height on month-to-month time scales. ENSO variability projects onto this mode on interannual time scales, but is not by itself a good predictor of Antarctic temperature anomalies. The third temperature mode explains winter warming trends, which may be caused by blocking events, over a large region of the East Antarctic plateau. These results help to place recent climate changes in the context of Antarctica's background climate variability and will aid in the interpretation of ice core paleoclimate records.

1. Introduction

A number of studies have shown considerable interest in identifying and explaining Antarctic temperature trends over recent decades (Doran et al. 2002; Marshall 2002a; Thompson and Solomon 2002; Vaughan et al. 2001; van den Broeke 2000a). However, because the interannual variability of Antarctic climate is large, it is difficult to establish the significance of surface temperature trends from sparsely distributed weather stations on the continent (King 1994). Furthermore, relatively little is known about the spatial structure of surface temperature variations across Antarctica. Such knowledge would, for example, improve the interpretation of ice core paleoclimate records, which are usually obtained from locations that are remote from weather stations.

Two important influences on Antarctica's climate variability, the Southern Annular Mode (SAM) and the El Niño–Southern Oscillation (ENSO), have been discussed by several studies, and increased tendency for these circulation patterns to stay in a particular phase may be driving surface temperature trends in the Antarctic (Gillett and Thompson 2003; Bromwich et al. 2003; Ribera and Mann 2003; Thompson and Solomon 2002; Kwok and Comiso 2002). We are therefore motivated to pay particular attention to the influence of these atmospheric patterns on Antarctic surface temperature anomalies, which, in this study, are derived from passive microwave brightness temperature (T_B) and thermal infrared satellite observations (T_{IR}).

In previous work with these data, Schneider and Steig (2002, hereafter SS) presented a principal component analysis of T_B data and showed evidence for the SAM and ENSO-related signals in Antarctica. However, the T_B data, taken alone, can be complicated to interpret because of the effects of nonstationary microwave emissivity variations due to variations in snow characteristics, and occasional surface melt events. Kwok and Comiso (2002) examined newly available T_{IR} data, and also linked their variability to the SAM and ENSO. That study assumed, a priori, that indices of the SAM and ENSO would have skill in describing surface temperature anomalies, but it found mixed results. For example, the Southern Oscillation index (SOI) does explain SST and sea ice anomalies well over the Southern Ocean, but it does not have good skill at describing temperature anomalies on the Antarctic continent. Also, as Comiso (2000) and Shuman and Comiso (2002) dis-

* Additional affiliation: Quaternary Research Center, University of Washington, Seattle, Washington.

Corresponding author address: David Schneider, Department of Earth and Space Sciences, University of Washington, Box 351310, Seattle, WA 98195.
E-mail: schneidd@u.washington.edu

cuss, the T_{IR} dataset is biased by the absence of data for days with cloud cover. Shuman and Comiso was the first study to directly compare T_{IR} and T_B data and generally found good agreement, but it only made comparisons at a few isolated locations with weather stations. Given the sparse distribution of Antarctic weather stations, it is desirable to further examine Antarctic climate with these satellite data. Other gridded products, such as the National Centers for Environmental Prediction–National Center for Atmospheric Research (NCEP–NCAR) reanalysis data, are significantly less reliable for Antarctic climate studies, especially for surface conditions (Marshall 2002b; Hines et al. 2000).

In this paper, we analyze the T_{IR} and T_B data in order to reduce uncertainties in interpreting either satellite dataset alone. First, we evaluate the T_{IR} data with methods that optimize the amount of variance that can be explained, in parallel to SS. Second, we use the two types of data to estimate the magnitude of microwave emissivity fluctuations. Next, the data are evaluated jointly using maximum covariance analysis (von Storch and Zweirs 1999). The results of this analysis increase confidence in the interpretation of both datasets in terms of surface temperature variability. We examine the relationship between surface temperature variability and atmospheric circulation through comparison of the empirical modes of the satellite datasets with NCEP–NCAR geopotential height data. We conclude that, overall, the SAM explains the greatest variance in Antarctic temperatures. However, the second most important influence is not simply described by ENSO, but rather, reflects a combination of patterns previously referred to as the Pacific–South American and wavenumber-3 patterns. We also suggest that blocking may be responsible for driving strong temperature trends in a little-studied region (0°–90°E) of East Antarctica.

9. Discussion and conclusions

Previous studies have shown that Antarctic 37-GHz T_B data and T_{IR} data are both well correlated with surface air temperatures (Shuman and Comiso 2002; Surdyk 2002; Shuman and Stearns 2001; Comiso 2000), but this is the first to fully examine the consistency of these relationships across the continent. The PCA and MCA results demonstrate that the most important empirical modes in the T_{IR} and T_B datasets are well correlated with each other. The strength of the connection between T_{IR} and T_B increases confidence in the quality of both datasets. A general difference between the datasets is that the T_B data are more spatially varying and more temporally autocorrelated than the T_{IR} data because of the dependence of T_B on both emissivity and temperature integrated over a layer of snow and firn. The degree of dampening of T_B signals depends on the period of the surface forcing and the penetration depth of the microwave emission. Lower emissivity regions indicate a shallow penetration depth and relatively high amplitude T_B fluctuations, which results in the highest T_{IR} and T_B covariance. The spatial pattern in emissivity apparently changes very little in time, and most likely represents spatially differing snow and firn structures.

Spatial and temporal patterns of T_{IR} and T_B variability, and more generally, surface temperature variability, in Antarctica are consistent with well-documented patterns of variability in extratropical SH atmospheric circulation. It is clear that the most important influence on Antarctic temperature anomalies from month-to-month to interannual time scales is the SAM. This first mode is well separated from other modes in both $Z500$ data and the satellite datasets. Looking at data from all months, strong temperature trends associated with this mode are not seen. However, inspection of trends by month over the length of the record shows that T_{IR} observations are consistent with a late spring and summer cooling trend, possibly driven by an increasing tendency of the SAM to stay in its positive phase during these seasons (Thompson and Solomon 2002).

The PSA pattern has an influence on the first two surface temperature modes. The wavenumber-3 pattern of variability, however, has a relatively stronger influence on the second surface temperature mode, shown by its association with large temperature anomalies in the West Antarctic sector inland of the Ross and Amundsen Seas. Anomalies of opposite sign in East Antarctica suggest that the PSA pattern exerts a stronger influence there. Since ENSO-related variability projects primarily onto the PSA and the wavenumber-3 patterns, Antarctic climate records often show ENSO-like spectra (SS; Ichiyanagi et al. 2002; Bromwich and Rogers 2001; White et al. 1999).

Some persistent trends in the available satellite record are associated with the third mode, which cannot, within the scope of this study, be clearly linked to the principal patterns of atmospheric circulation variability. However, blocking events over inland East Antarctica have been documented with station data (Hirasawa et al. 2000; Enomoto et al. 1998) and provide a plausible explanation for the trends in temperature and the pattern seen in $Z500$ on our regression map (Fig. 9c). During these episodes, rises of $\sim$40 K can occur in two days or less at remote interior stations such as Dome Fuji and Plateau, and T_a can take more than a month to return to its value before the rise (Enomoto et al. 1998; Kuhn et al. 1973). The upward trend in the T_{IR} and T_B expansion coefficients comes primarily from the winter months, when the blocking episodes most often occur and the surface temperature is extremely sensitive to circulation changes. In addition, changes in cloud cover and winds associated with blocking will destroy the surface inversion, adding to the magnitude of the surface temperature anomalies (Hirasawa et al. 2000). At present, however, the satellite record is too short to establish the long-term significance of the trends, and the monthly temporal resolution of this study limits our ability to further characterize the causes of variability in the third temperature mode.